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## Effects of Collision Avoidance System on Driving Patterns in Curve Road Conflicts

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### Abstract

Studies of collision avoidance system (CAS) are usually implemented by applying driving simulator or observing normal car following procedure. In order to understand its effect on drivers' driving patterns under real world curve road conflict condition, this study carried out more than 500 tests with 55 drivers on a test road curve. By comparing the test results from CAS and non-CAS datasets, it was found that drivers drove slower and decelerate lighter after CAS was turned on. In addition, this study identified three types of driver in terms of safety performance of their brake and deceleration behaviors before encountering a road obstacle. It was found that many drivers became drivers with better driving patterns by the assistance of the CAS. These findings provided a quantitative understanding of the safety benefit from the application of CAS.

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**Keywords:** collision avoidance system; safety influences; surrogate safety indicator; curve road conflict.

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## 1. Introduction

The collision avoidance system (CAS) is a part of the advanced driving assistance system. It detects road obstacles and helps drivers avoid the potential collision by sending video and audio warning messages and/or controlling driving wheel and brake when necessary. Currently studies of CAS mainly focus on the development and test of CAS control algorithms (Isermann et al., 2012; Milanés et al., 2012; Desraj, 2009; Moon et al., 2009), navigation and communication (Taleb et al., 2010; Santa et al., 2010), obstacle detection and system activation timing (Tang and Yip, 2010; Wada et al., 2010). However, CAS's effects on drivers' actual deceleration and obstacle avoidance patterns are rarely reported, largely due to lack of method for collecting real world driving profiles in conflict conditions.

Itoh et al. (2010) recruited 20 drivers in order to test the influences of a forward obstacle collision avoidance system in a driving simulator. It was found that the number of collisions and the minimum time to collision (TTC) was significantly reduced by the system. Since the tests were performed in a driving simulator, the effects of CAS in real world traffic cannot be reflected by the study results. The study reported by Adell et al. (2011) implemented several real world driving tests, in which the performance of test drivers were recorded by two onboard observers. The authors found positive effects of the CAS in terms of fewer alarm situations, shorter alarm lengths, shorter reaction times, increased headway and better interactions with vulnerable road users at intersections. Similarly Ben-Yaacov et al. (2002) carried out a CAS test on a six-lane highway with 30 participants. The test drivers were asked to follow a random vehicle and try their best to keep the safe headway in several trails either with or without CAS. The study found out that the presented CAS was able to help drivers keep safe headway and estimate headway accurately. However, the tests in these studies were performed in a normal car following condition. They didn't provide sufficient data to reveal drivers' responses in conflict or near collision cases, which are the very circumstances the CAS should be utilized in.

In order to address the identified problems, the goal of this research is to evaluate the influences of CAS on drivers' driving patterns during road curve conflict condition by using real world driving data. The goal has been achieved by first performing a sophisticated CAS test procedure on a test road. The test data were collected and analyzed so that surrogate safety indicators were extracted from tests with CAS and tests without CAS. By comparing the safety indicators from both datasets, the effects of CAS were finally revealed and presented in this paper.

## 2. Test Development and Data Collection

Two types of tests, i.e., tests with CAS and without CAS, were designed and performed in this study. The CAS includes an onboard module and a road side module. The road side module monitors a two-lane curve road through video sensors. If an obstacle is identified, the obstacle information (e.g., type, location and speed of the obstacle) is sent to the onboard module. The onboard module then warns the driver by announcing the type and distance of the obstacle through video and audio warning messages. Then the driver executes necessary maneuvers to avoid hitting the obstacle.

The tests were performed in a two lane road curve in a test field (as shown in Fig. 1). During each test, a vehicle (called incident vehicle) first traveled onto the road curve and then slowed down to stop at a random location. The occurrence of the vehicle stop was considered as an artificial traffic incident and the incident vehicle became a road obstacle for the following traffic. A driver (called test driver) was required to drive another vehicle (called test vehicle) to follow the incident vehicle in about 500-meter distance. Because of the small curve radius of the test road, the test driver had limited sight distance and thus could not see the entire event of

incident vehicle stopping during the following process. The artificial traffic incident then became a surprise to the test driver and the CAS was believed to be very helpful under such circumstance. The test drivers' braking responses and speed profile were recorded by the on-board high resolution GPS and brake sensor in each test run.

Totally 55 drivers (53 male and 2 female) were recruited for the tests. These drivers were professional drivers (taxi drivers and commercial truck drivers) and most of them had been driving for at least 5 years. Apart from 8 drivers that were older than 50 years, all other drivers were between 20 to 50 years old. Each driver was involved in 10 tests. Among the 10 tests, 1 test was performed when the CAS was turned on and the incident vehicle was not stopped on the test road; 1 test with the CAS turned off and without the incident; 4 tests with the CAS turned on and the incident on road; and the rest 4 tests with the CAS turned off and with the incident on road. The first two tests (tests without incident vehicle) were used as 'dummy tests'. After introducing them, the test drivers had difficulty in predicting the occurrence of the artificial incidents and thus were forced to drive in their natural way. The remaining 8 tests provided data for estimating the effects of CAS. After all tests, there were 505 valid data samples collected from the field tests. In each sample file, the test vehicle's speed, location, and braking status were stored every 0.1 second. In addition, the location where the incident vehicle stopped was also recorded.

In order to avoid that the tests results were biased across and between experiments, the tests were designed so that the same group of drivers participated in the 10 tests in a random order. The random test procedure prevented the test drivers from predicting the occurrence of the artificial traffic incident and thus compelled them drive in their normal nature. Also the same group of drivers was required to participate in all tests (with and without the CAS). It ensured that the undesired unknown factors that lead to biased observations existed in all data samples. Thus the effects of these factors can be substituted when results from CAS and non-CAS datasets are compared. In addition, multiple tests could provide multiple observation records for individual test driver and thus the effects of error on one driver's results can be reduced by averaging the records.

### 3. Surrogate Safety Indicators

Surrogate safety indicators (as shown in Table 1) were applied in this study to reveal the safety influence of the CAS. The indicators reflect traffic safety by measuring traffic parameters that relate to road accident occurrence (such as traffic conflicts) instead of measuring number of road accidents directly. These indicators were used in this study because they happened more frequently than accidents and could be observed during the tests. In addition, they were able to provide insight into the failure mechanism that led to road accidents (Autey et al., 2012).



Fig. 1. The test road curve

Table 1. Surrogate safety indicators used in this study

Indicators	Notes
Mean speed (m/s)	The average speed within 20 seconds before the test driver passes the obstacle. When the value turns smaller, it indicates the driver would have more time to avoid the potential collision with the obstacle.
Brake distance (m)	The distance between the test vehicle and the obstacle when the driver steps on the brake paddle. If the driver brakes several times during the test, the distance is measured at the brake location that is closest to the obstacle.
Brake speed (m/s)	The instance speed when the test driver brakes. If the driver brakes several times during the test, the speed is measured at the brake location that is closest to the obstacle.
TTC (s)	Time-to-collision. It is defined as “. . . the time that remains until a collision between two vehicles would have occurred if the collision course and speed difference are maintained” (Hayward, 1972). In this study, TTC is calculated during the each test process by Equation (1): $TTC_i = \frac{X_{i-1}(t) - X_i(t) - l_i}{\dot{X}_i(t) - \dot{X}_{i-1}(t)} \quad \forall \dot{X}_i(t) > \dot{X}_{i-1}(t) \quad (1)$ <p>where <math>\dot{X}</math> is the speed; <math>X</math> is the position, and <math>l</math> is the vehicle length.</p>
TET (s)	Time exposed time-to-collision, the total amount of time during which the test vehicle's TTC is below certain threshold in the observation period (Minderhoud & Bovy, 2001). In this study, the threshold is 2 seconds and the observation period is 20 seconds before the test vehicle passes the obstacle. Fig. 2 illustrates the calculation of TET.

The individual TTC value is only able to depict the conflict condition between a leading and a following vehicle at a time point. Usually if TTC is less than a threshold value (2 seconds in this study, as suggested by Minderhoud & Bovy, 2001), the corresponding condition is considered as severe conflict that may lead to actual accident. However, the TTC value cannot show safety performance of the collision avoidance process in a period of time. On the other hand, TET, as an indicator derived from TTC, can not only indicate the traffic conflict of each test as TTC does, but also record the duration of several conflict each driver has exposed. Therefore, this study adopts TET instead of TTC as the major traffic conflict indicator.

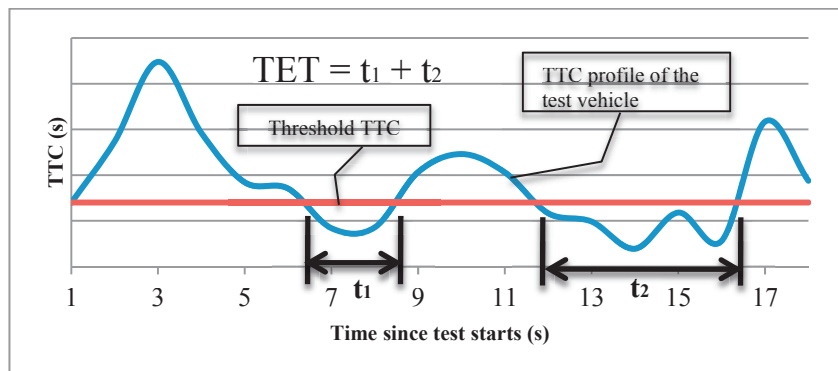


Fig. 2. Calculation of TET

#### 4. Results

The speed profile and brake data from both with and without CAS datasets were analyzed. As Fig. 3 shows, the speed data for both with CAS and without CAS tests are averaged in every second during the 20 seconds period before the test vehicle passes the obstacle. The figure shows that the speed in each second in CAS dataset is generally smaller than that in non-CAS dataset. The change of CAS speed (i.e., slope of blue line in Fig.3) is also smoother than that of non-CAS speed. It indicates that CAS helps drivers drive more slowly and decelerate more smoothly during the process of collision avoidance. It is very possible that the drivers, with the assistance of CAS, would act earlier to address the road obstacle and have more time to avoid the potential collision.

CAS also has significant influence on drivers' TET. The TET analysis results indicate that the mean TET with CAS is 0.17 seconds smaller than TET without CAS. The t-test confirms that the difference is statistically significant. It suggests that if CAS is turned on during the collision avoidance process, a driver would experience 0.17 seconds less in unsafe condition (when TTC is less than 2 seconds). The 6.9% improvement would make the collision avoidance process easier and safer.

CAS also changes the percentage of driver types so that more drivers are driving in the better pattern. The 0.1 second-by-0.1 second braking profile suggests that some of the test drivers had brake process during their tests while others not. It indicates that there are at least two types of drivers: brake drivers and non-brake drivers. Moreover, Fig. 4 shows brake drivers' brake speed vs. brake distance diagram. The figure reveals that there are two types of brake driver. The first type of driver takes the brake close to the stopped incident vehicle and their mean braking speed is about 12.5 m/s (data points on the left side of the boundary line in Fig. 4). The second type of driver brakes relatively far from the incident vehicle and the brake speed is about 15.5 m/s (data points on the right side of the boundary line in Fig. 4). If a vertical line is drawn at the 100 m position, the line is able to separate the two types of driver. To this end, three types of driver are identified, i.e., non-brake driver, far brake driver and close brake driver. As later session shows, the non-brake drivers have the least chance to collide with the obstacle among the three, while the close drivers have the largest chance.

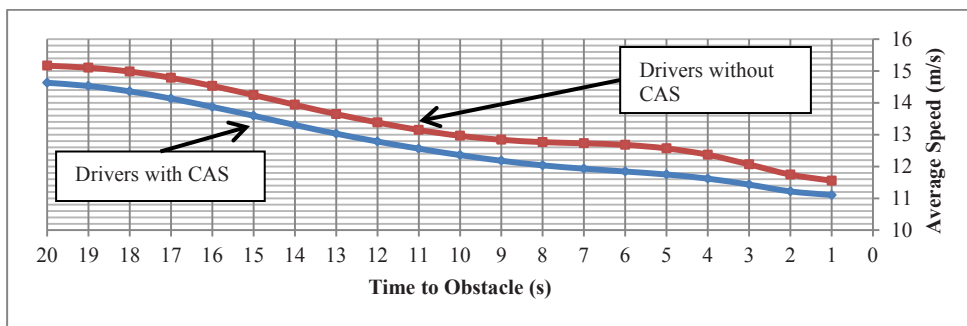


Fig. 3. Average speed vs. time to obstacle (all drivers)

Table 2. TET comparison between with and without CAS cases

	With CAS	Without CAS
Mean TET (s)	2.29	2.46
T-test p value (in 95% significance interval)	0.0044	

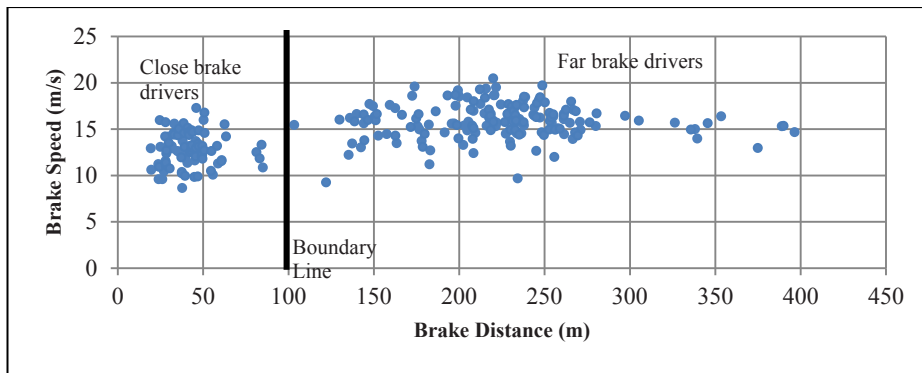


Fig. 4. Brake speed vs. brake distance

For the non-brake drivers, it is believed that they are cautious drivers and tend to keep the speed change as smooth as possible. The far brake drivers are similar. They have decent average speed and deceleration pattern. To the contrary, the average speed for close brake drivers changes drastically from 16 m/s to 10 m/s in both CAS and non-CAS datasets. Especially at the end of the collision avoidance process, the slope of the speed curve has a sudden increase, meaning a hard brake happens. Fig. 5 and Fig. 6 support the observation by comparing average speed among close brake drivers, far brake drivers and non-brake drivers.

Table 3 shows the fraction of different types of drivers in CAS and non-CAS tests. It shows that the percentages of non-brake driver, far brake driver and close brake driver are 32.3%, 40.4% and 27.3% when the CAS is turned off; and the percentages are 39.7%, 44.2% and 16.1% when the CAS is turned on. In other words, more drivers become non-brake and far brake drivers when the CAS is turned on. It indicates that for the same driver group, the CAS is able to make more drivers drive in the better patterns.

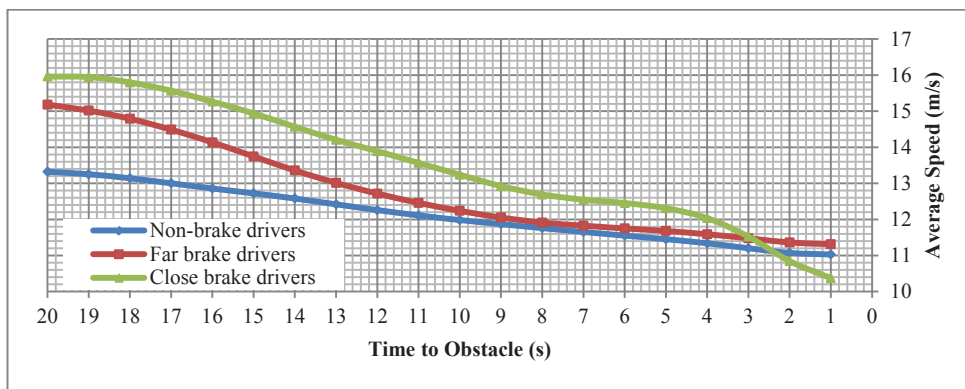


Fig. 5. Average speed vs. time to obstacle (CAS data)

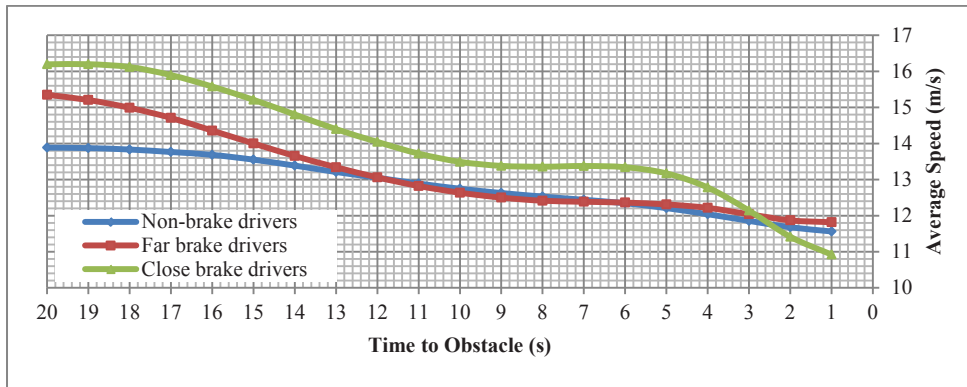


Fig. 6. Average speed vs. time to obstacle (No CAS data)

Table 3. Fraction of different types of driver

	# of drivers without ADAS	# of drivers with ADAS
Non-brake drivers	64 (32.3%)	79 (39.7%)
Far brake drivers	80 (40.4%)	88 (44.2%)
Close brake drivers	54 (27.3%)	32 (16.1%)

## 5. Conclusion

The study found out the effect of a collision avoidance system on drivers' driving pattern when they encountered an obstacle on a road curve. Through more than 500 tests on a test road section with 55 test drivers, it was observed that the CAS was able to make drivers drive slower and decelerate lighter than they did without CAS during the collision avoidance process. In addition, this study identified three types of driver in terms of their brake behavior before encountering the obstacle. Each driver either belonged to non-brake driver, far brake driver or close brake driver. The analysis of these drivers' speed profile revealed that the non-brake drivers had the smallest one second interval average speed and speed variation while the close brake drivers had the largest. The records from far brake drivers were moderate. Comparing CAS and non-CAS records from a same group of driver, it was found that more drivers turned to non-brake drivers or far brake drivers after CAS was turned on. These findings provided a quantitative understanding of the safety benefit from the application of CAS.

In the future, the presented CAS will be tested in real world traffic conditions with drivers from different demographic groups. Its effects on real world traffic incident will be identified from the study. Moreover, the future study will take into consideration the system's influence when different fractions of drivers are using the CAS. Such impact will be analyzed in simulation experiments.

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